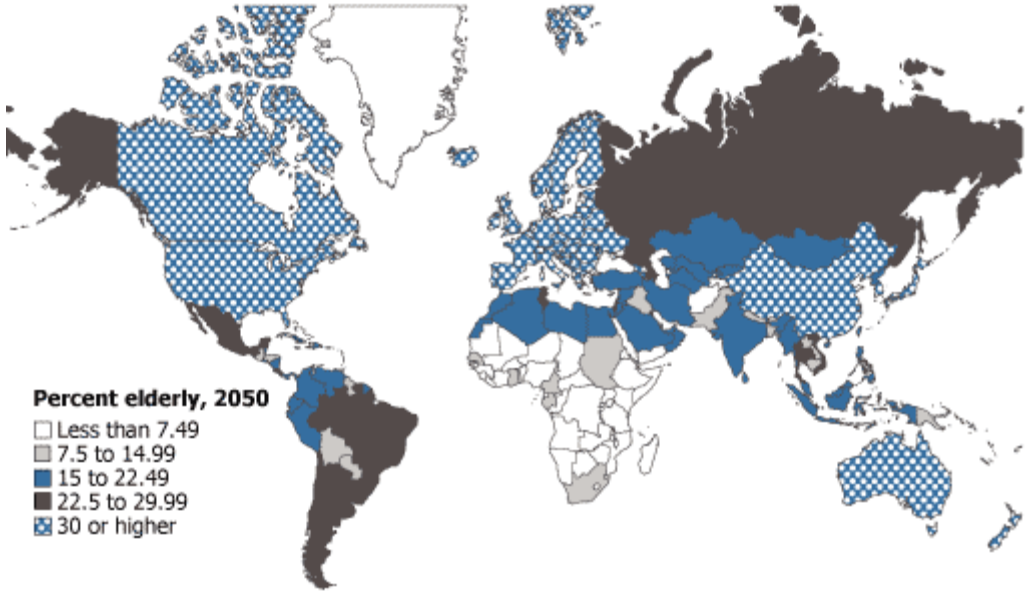
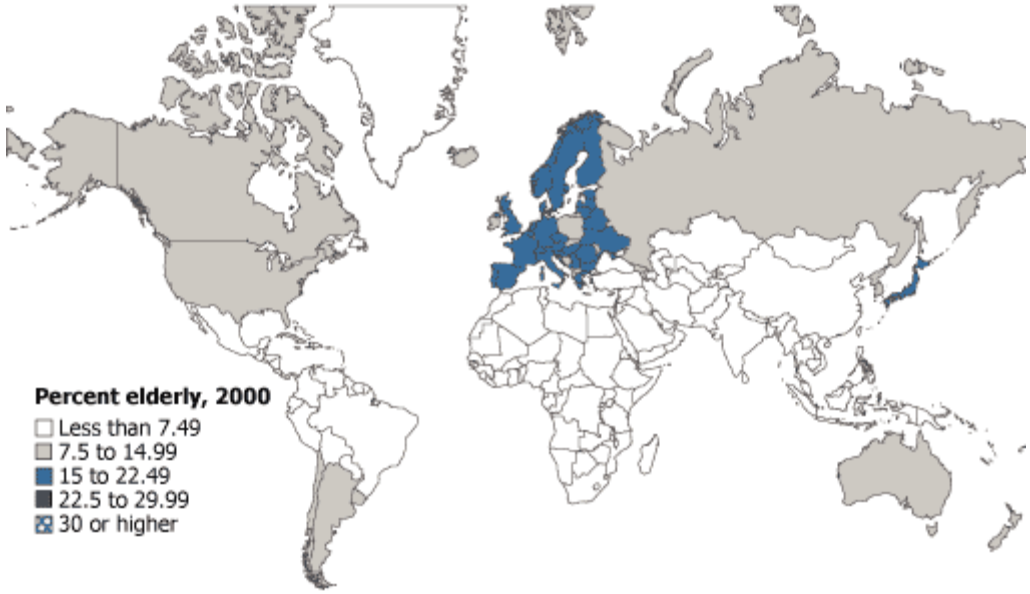
FET-based DNA biosensors

Corrado Napoli
corrado.napoli@diee.unica.it

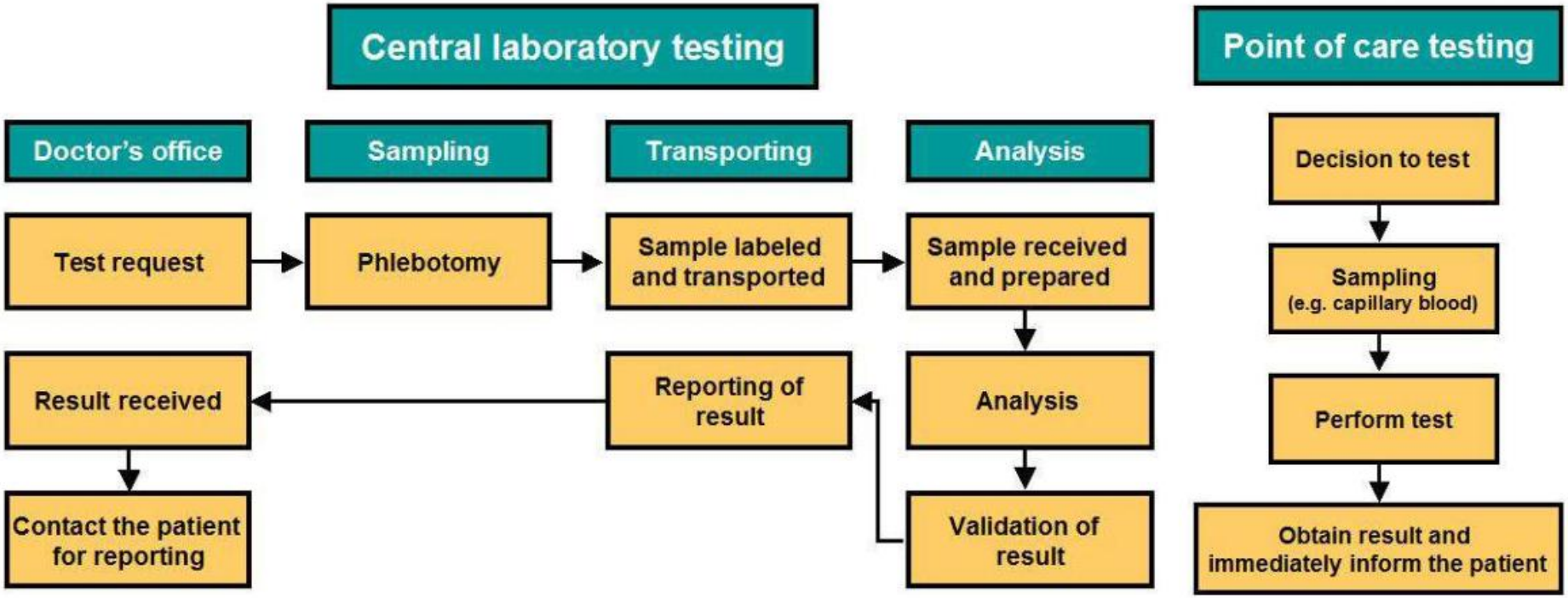
Motivation

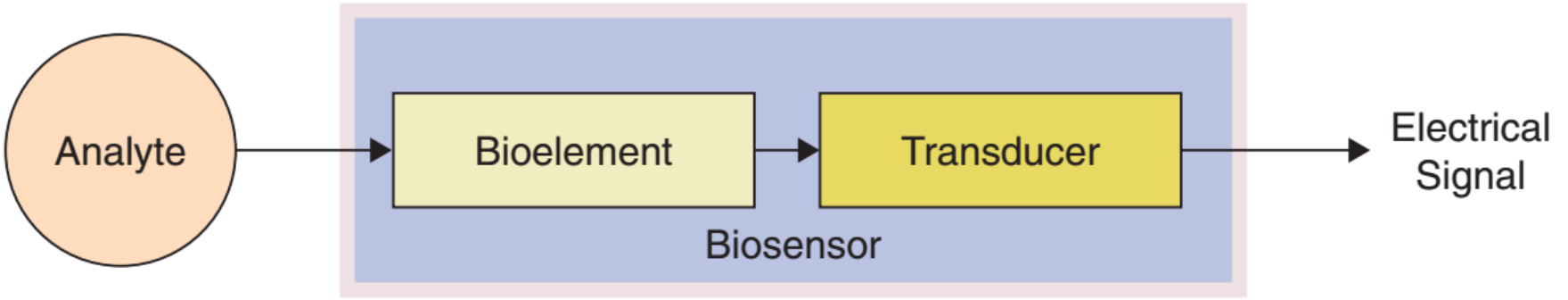

Percent elderly, 2050
Less than 7.49
7.5 to 14.99
15 to 22.49
22.5 to 29.99
30 or higher

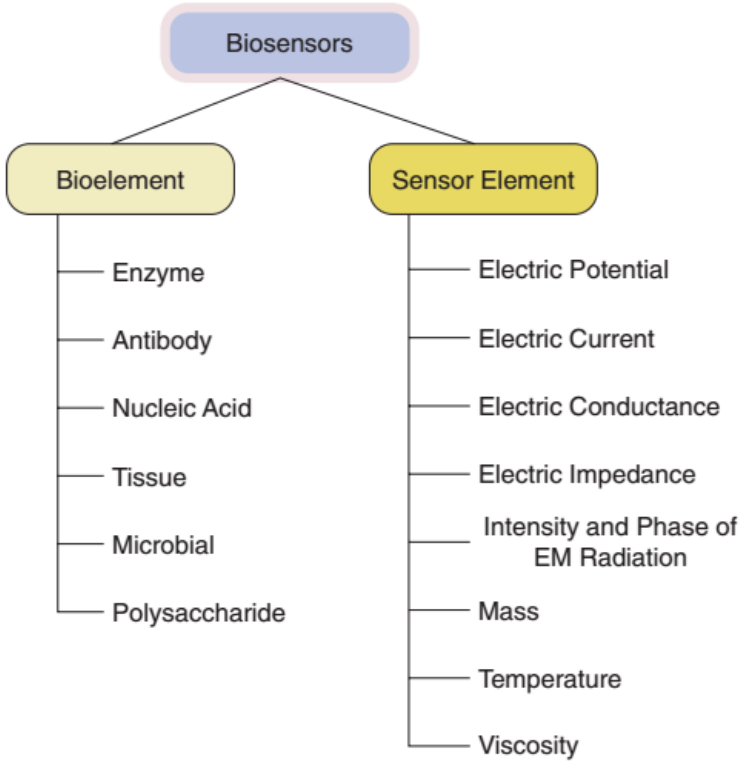
Motivation


Percent elderly, 2000
Less than 7.49
7.5 to 14.99
15 to 22.49
22.5 to 29.99
30 or higher

Motivation


Central laboratory testing
Point of care testing
Doctor's office
Sampling
Transporting
Analysis
Test request
Phlebotomy
Sample labeled and transported
Sample received and prepared
Result received
Reporting of result
Analysis
Contact the patient for reporting
Validation of result
Decision to test
Sampling (e.g. capillary blood)
Perform test
Obtain result and immediately inform the patient

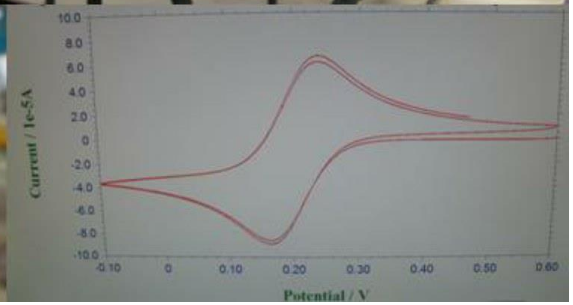


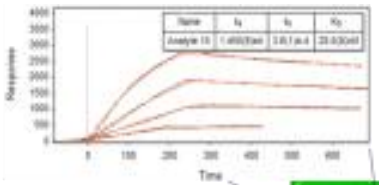


Def: A device that uses specific biochemical reactions mediated by isolated enzymes, immunosystems, tissues, organelles or whole cells to detect chemical compounds usually by electrical, thermal or optical signals. (IUPAC)

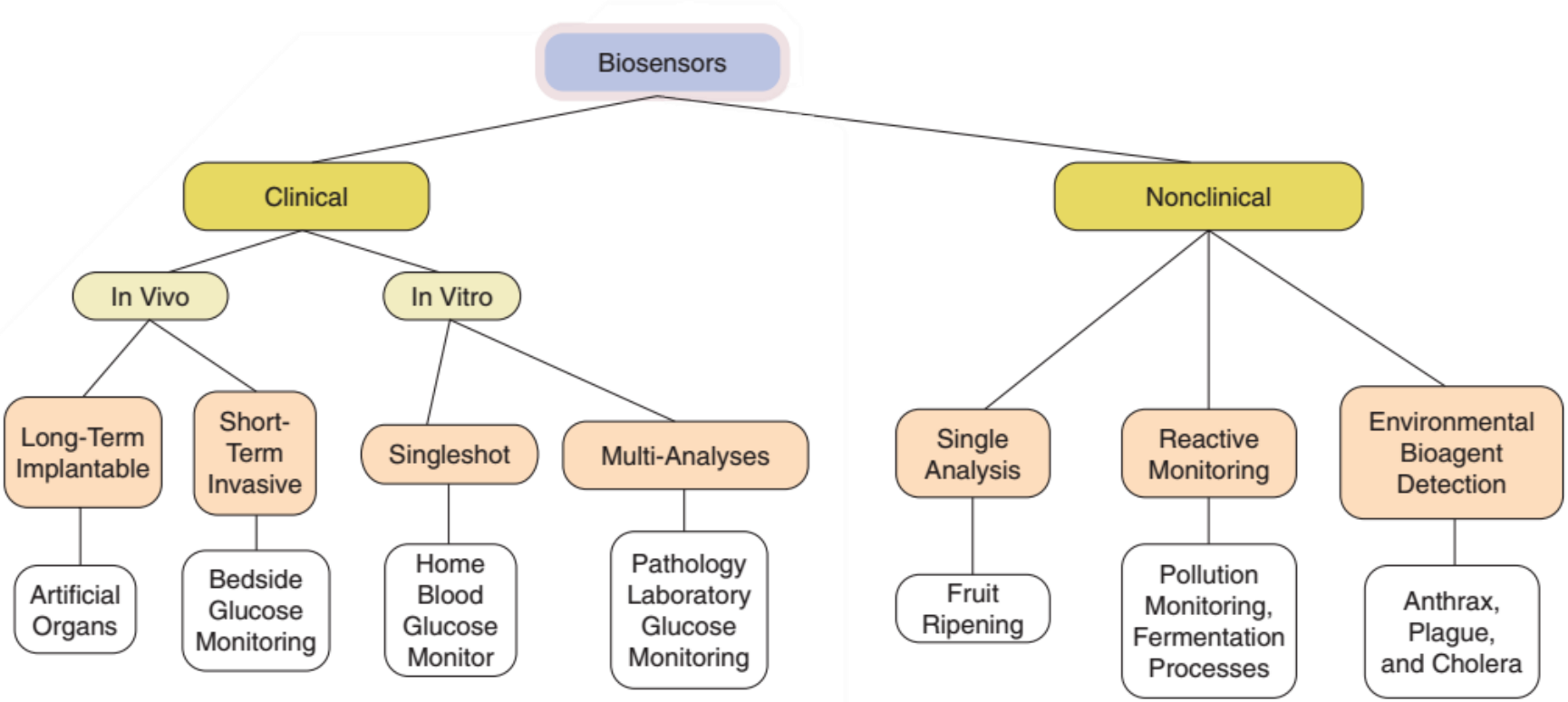
1

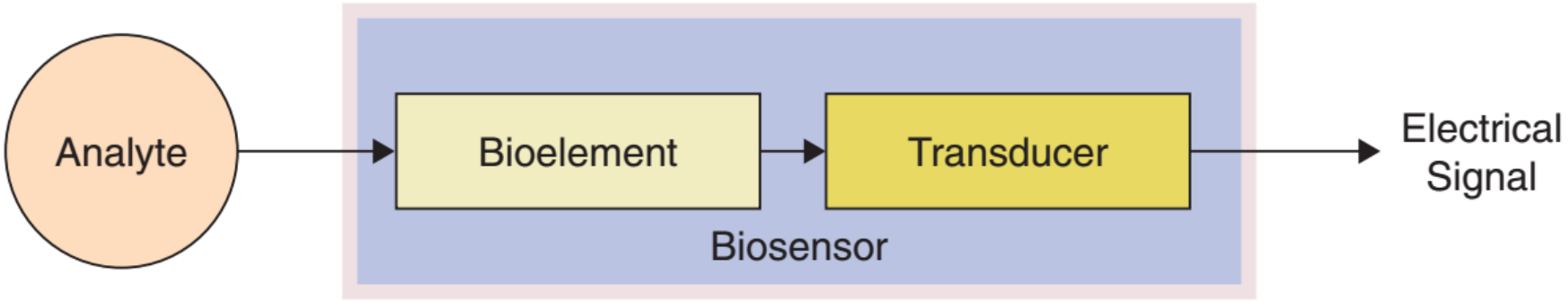

AUTOLAB
POTENTIOSTAT
GALVANOSTAT

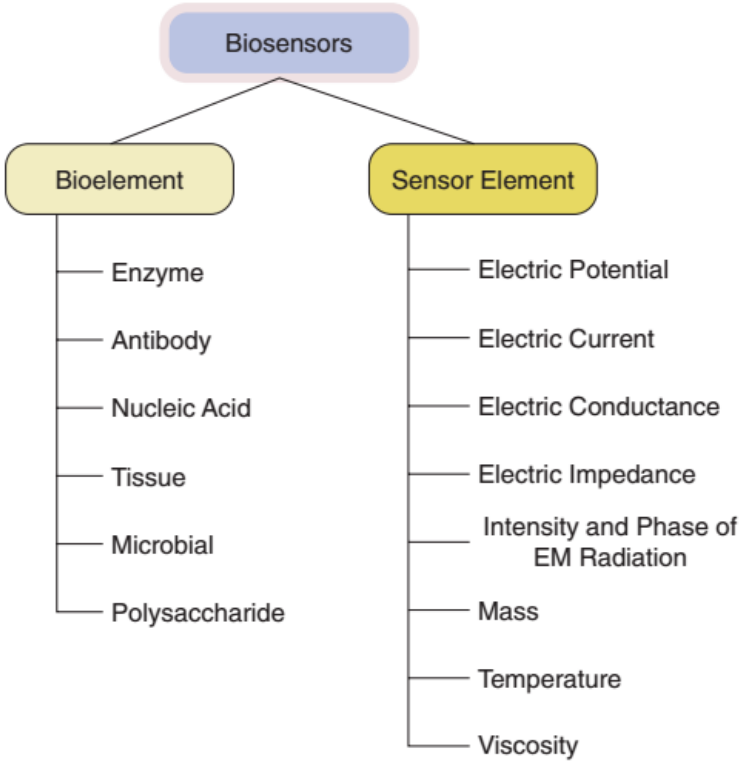

Current / 1e-5A
Potential / V
10.0
8.0
6.0
4.0
2.0
0
-2.0
-4.0
-6.0
-8.0
-10.0
-0.10
0
0.10
0.20
0.30
0.40
0.50
0.60


Time

Applications

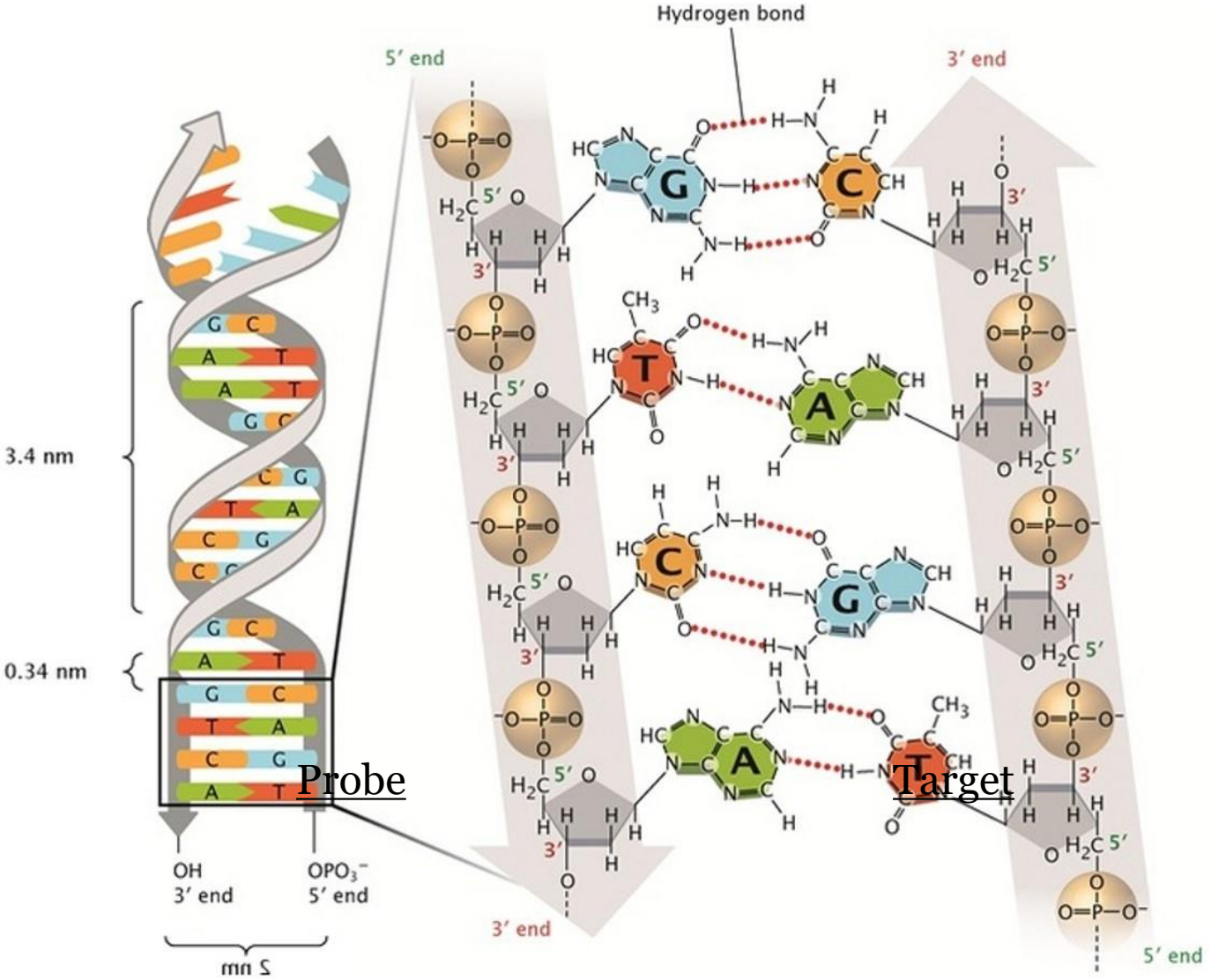


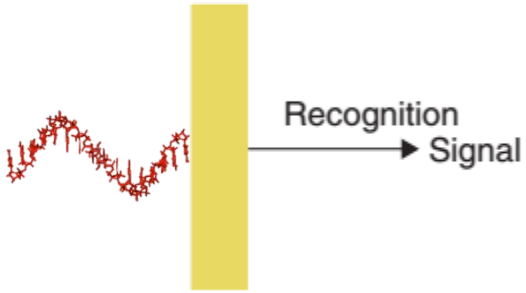




Transducer: FET → BioFET

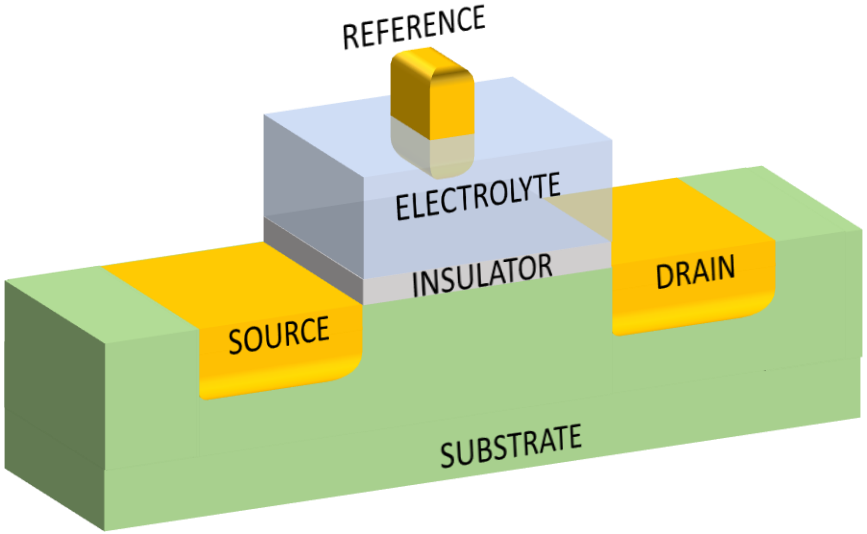
Biological element: DNA → GenFET


Hydrogen bond
5′ end
3′ end
3.4 nm
0.34 nm
Probe
Target
OH
3′ end
OPO3−
5′ end
3′ end
5′ end


Recognition
Signal

Why FET?

- Transistors:
  - Amplification
  - Label free



$$I_{DS} = f\left(\mu, C_{INS}, W, L, V_{GS}, V_{DS}, V_{TH}, R_C\right)$$

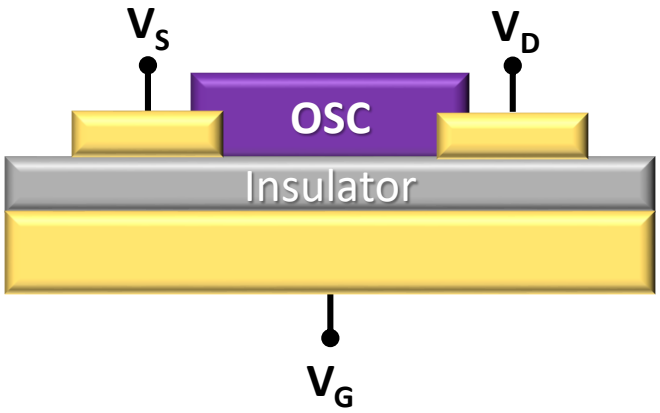
Sensing area:

- Gate/electrolyte
- Semiconductor
- Electrodes

Sensing mechanisms:

- Field effect modulation

Why OTFT?



- Transistors:
  - Amplification
  - Label free

$$I_{DS} = f\left(\mu, C_{INS}, W, L, V_{GS}, V_{DS}, V_{TH}, R_C\right)$$

- Materials:
  - Biodegradable
  - Biocompatible
  - Flexible
  - Cost effective
  - Large area production

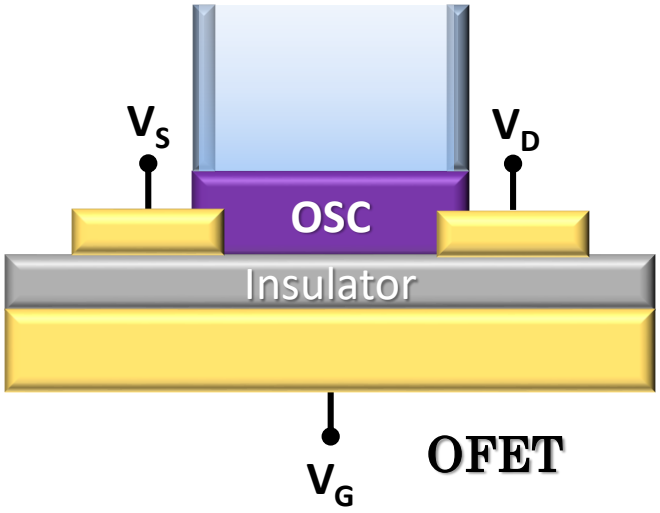
Sensing area:

- Gate/electrolyte
- Semiconductor
- Electrodes
- Active semiconductor/electrolyte

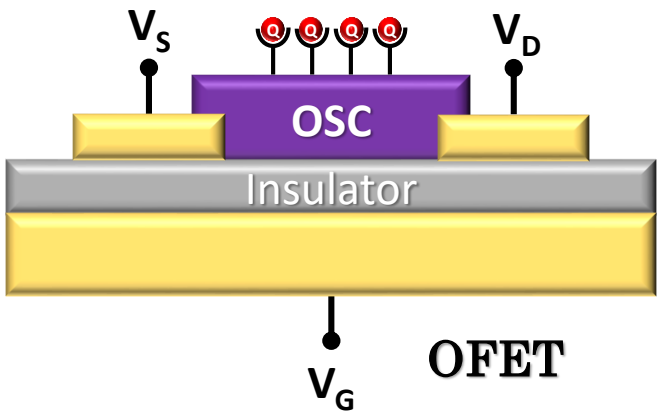
Sensing mechanisms:

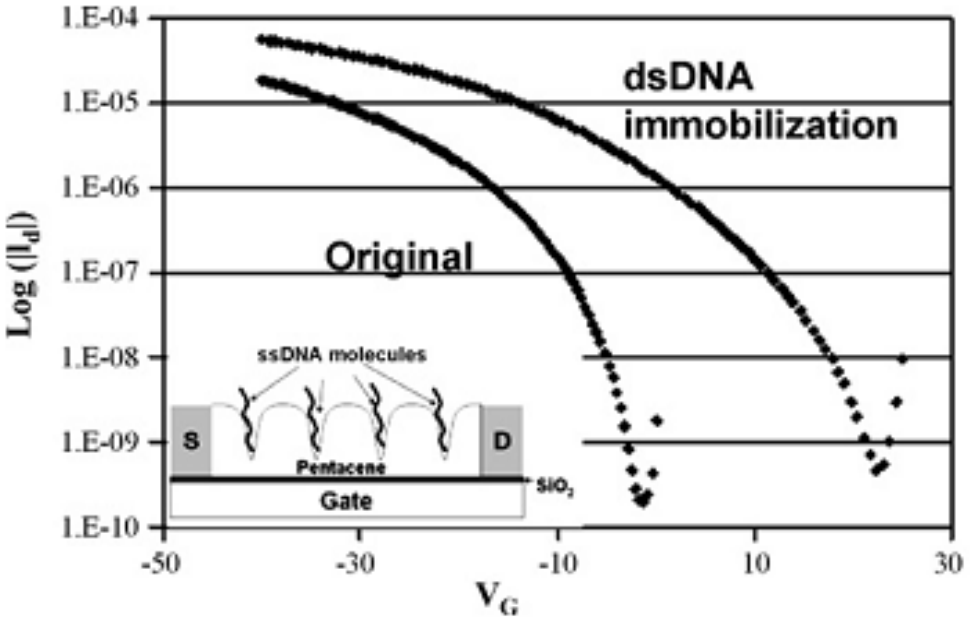
- Field effect modulation
- Morphology variation

Structures



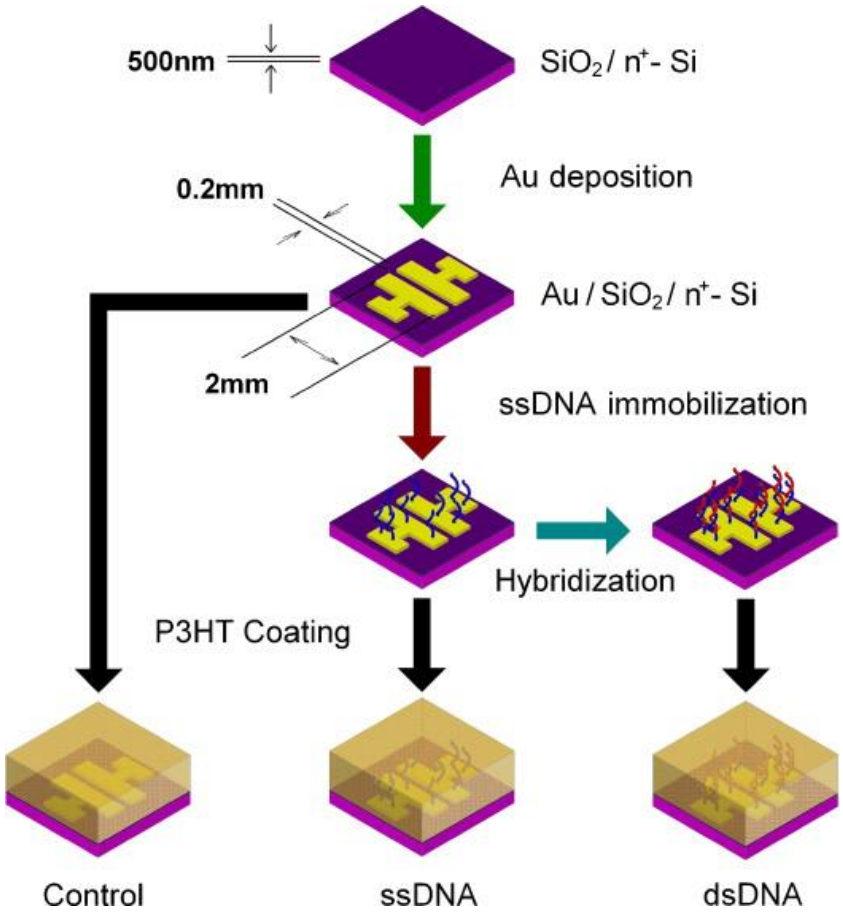
OSC functionalization

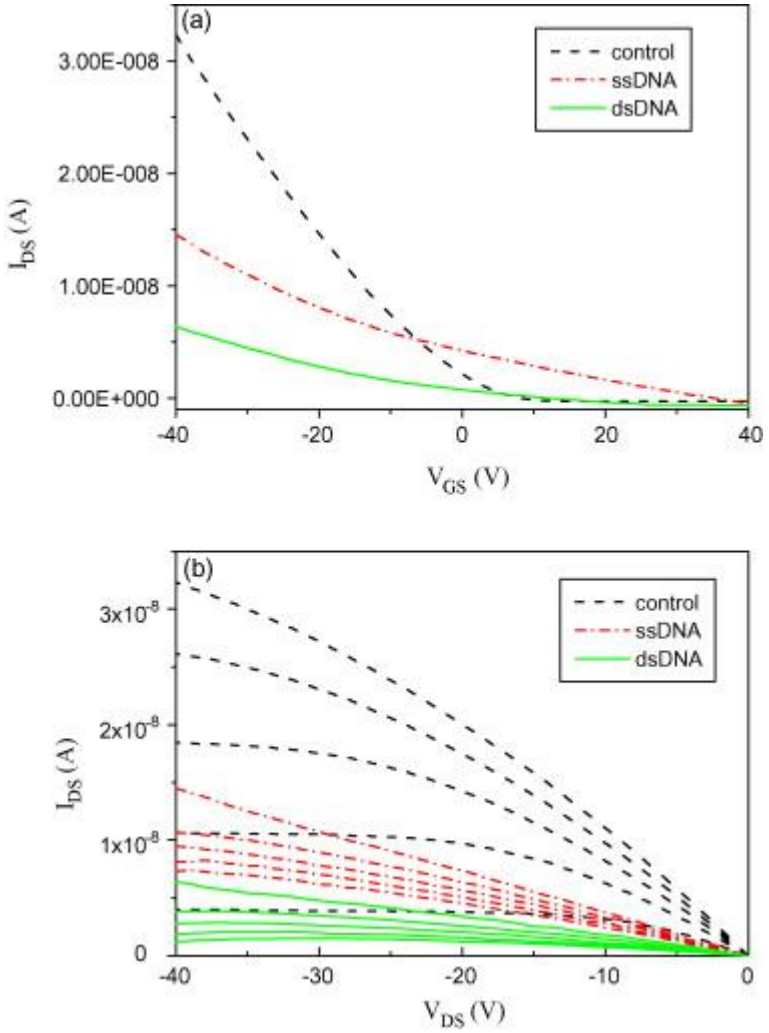




DNA hybridization detection with organic thin film transistors: Toward fast and disposable DNA microarray chips
Qintao Zhang, Vivek Subramanian (2007)

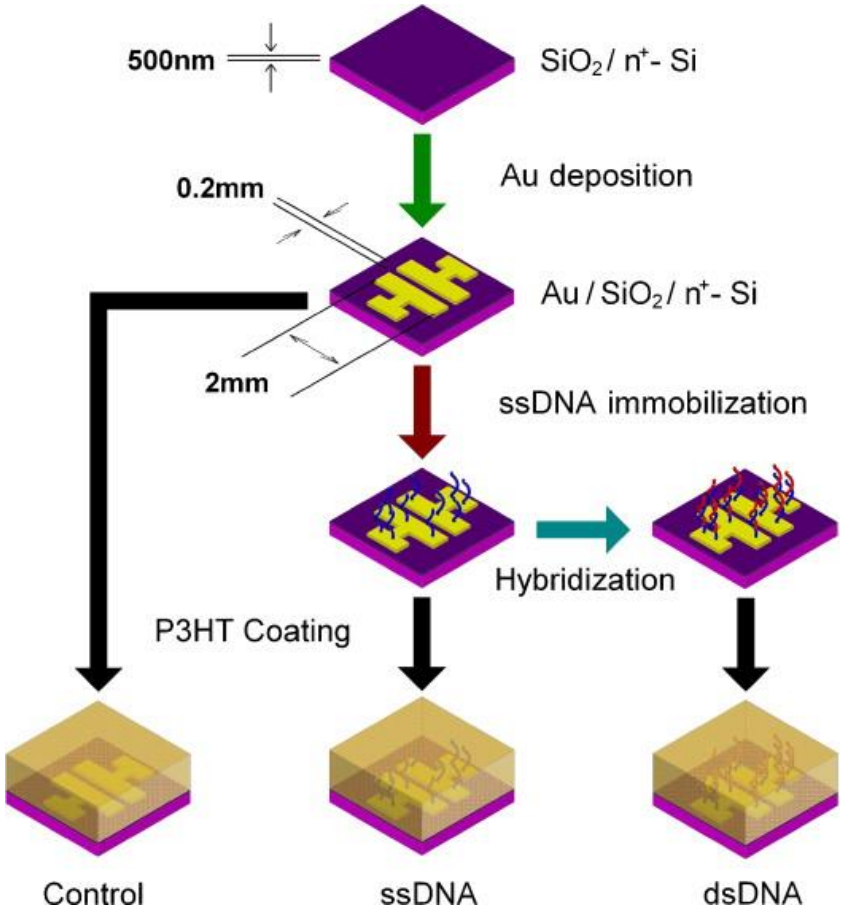
Charge injection modulation

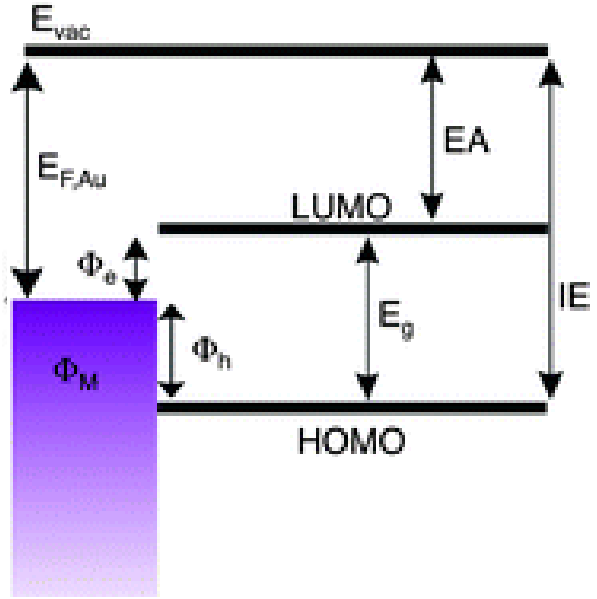




Label-free DNA sensor based on organic thin film transistors
Feng Yan, Sheung Man Mok, Jinjiang Yu, Helen L.W. Chan, Mo Yang (2009)

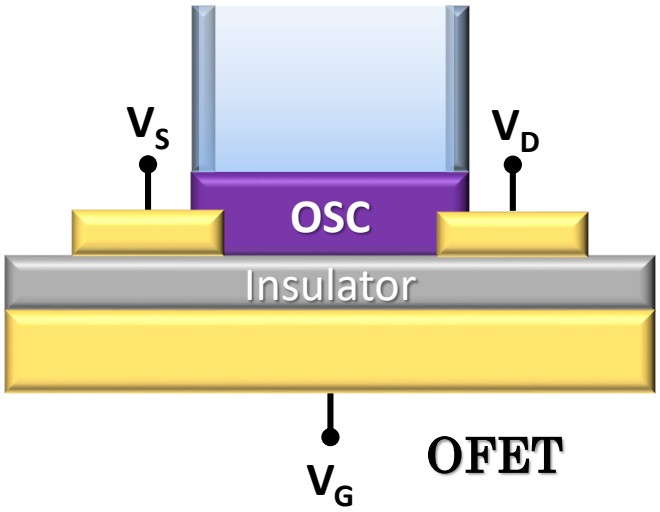
Charge injection modulation

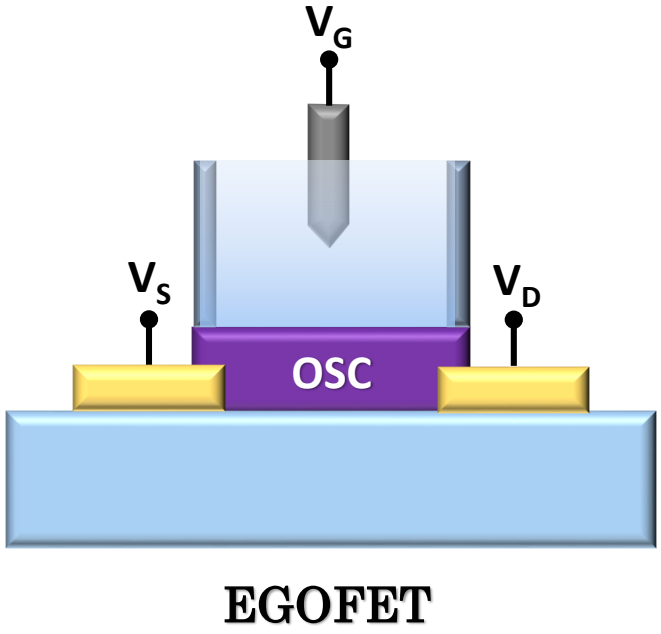




Label-free DNA sensor based on organic thin film transistors
Feng Yan, Sheung Man Mok, Jinjiang Yu, Helen L.W. Chan, Mo Yang (2009)

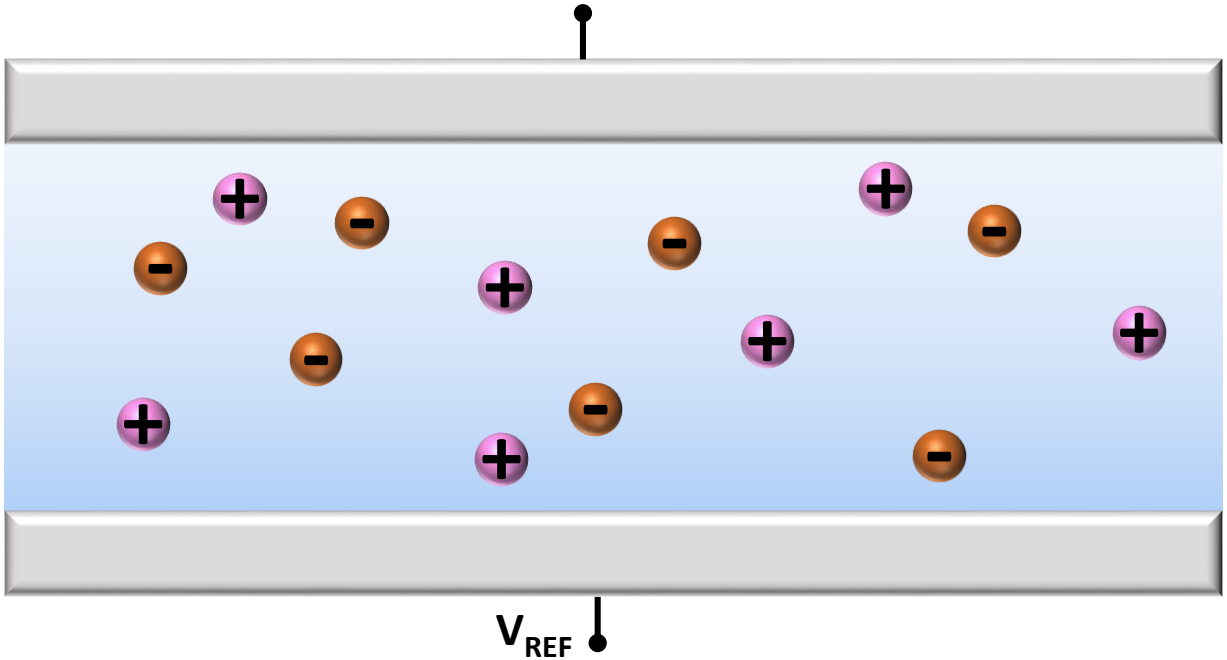
Structures

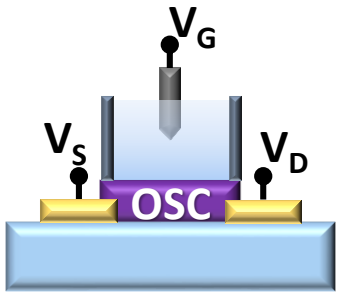




- Operating voltages
- Actual feasibility
- Stability

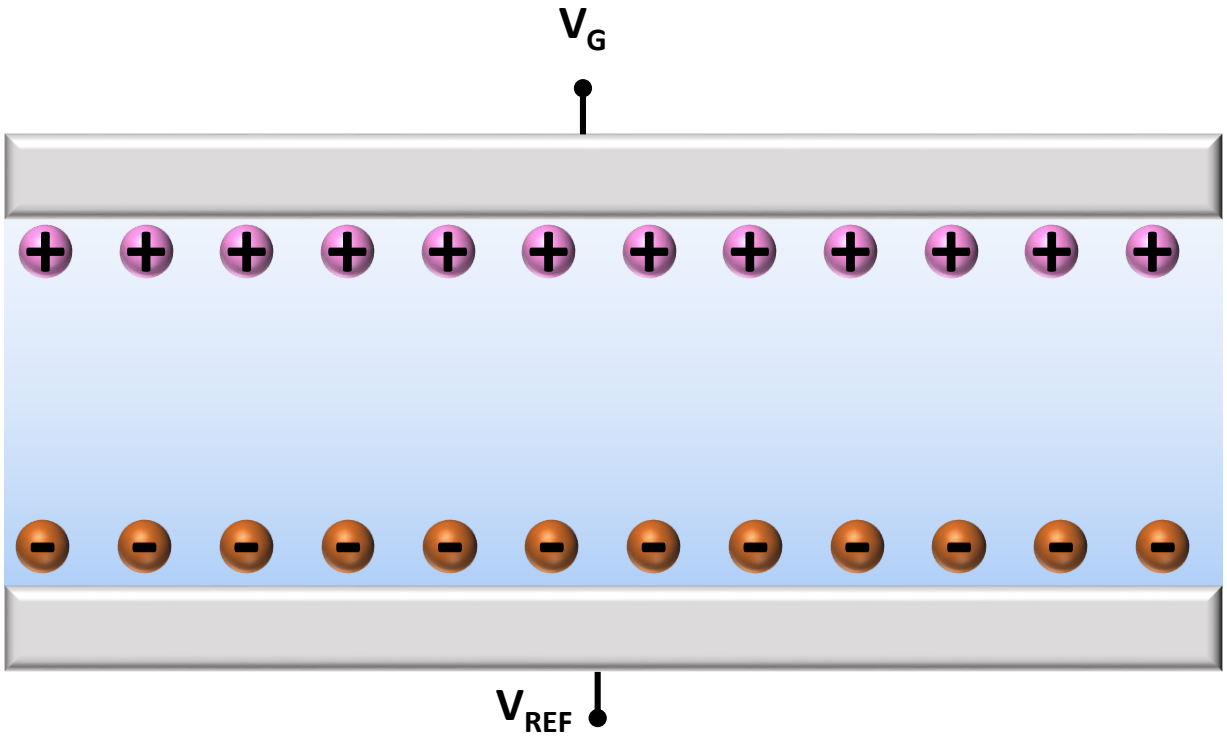
Electrolyte: polarization

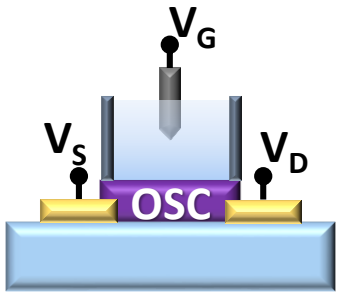




EGOFET

Electrolyte: polarization





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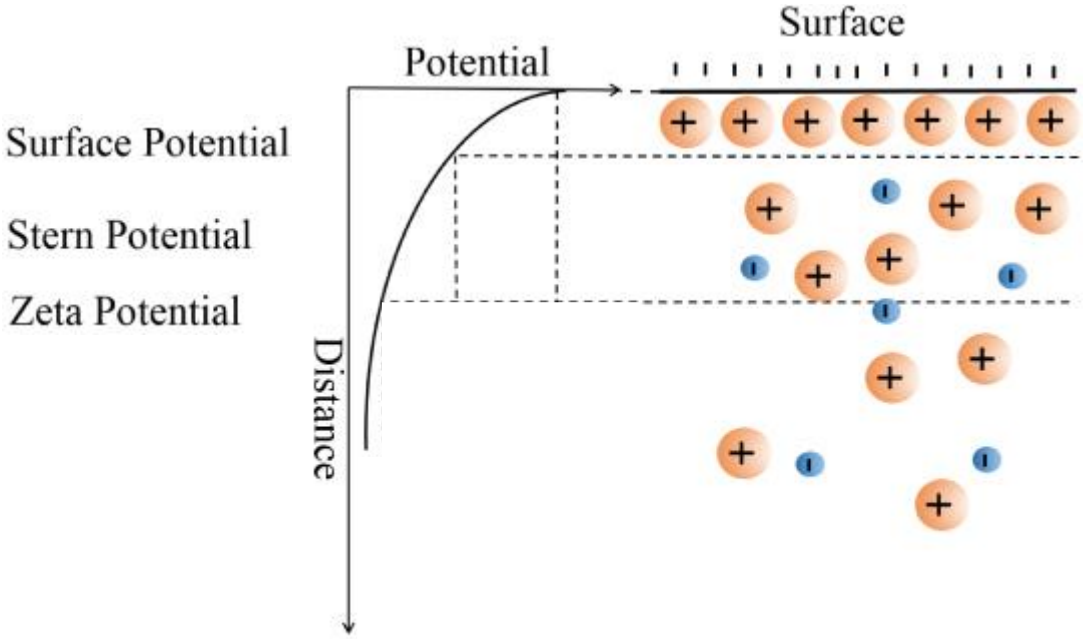
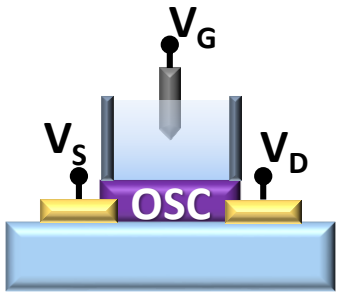
Electrolyte: double layer



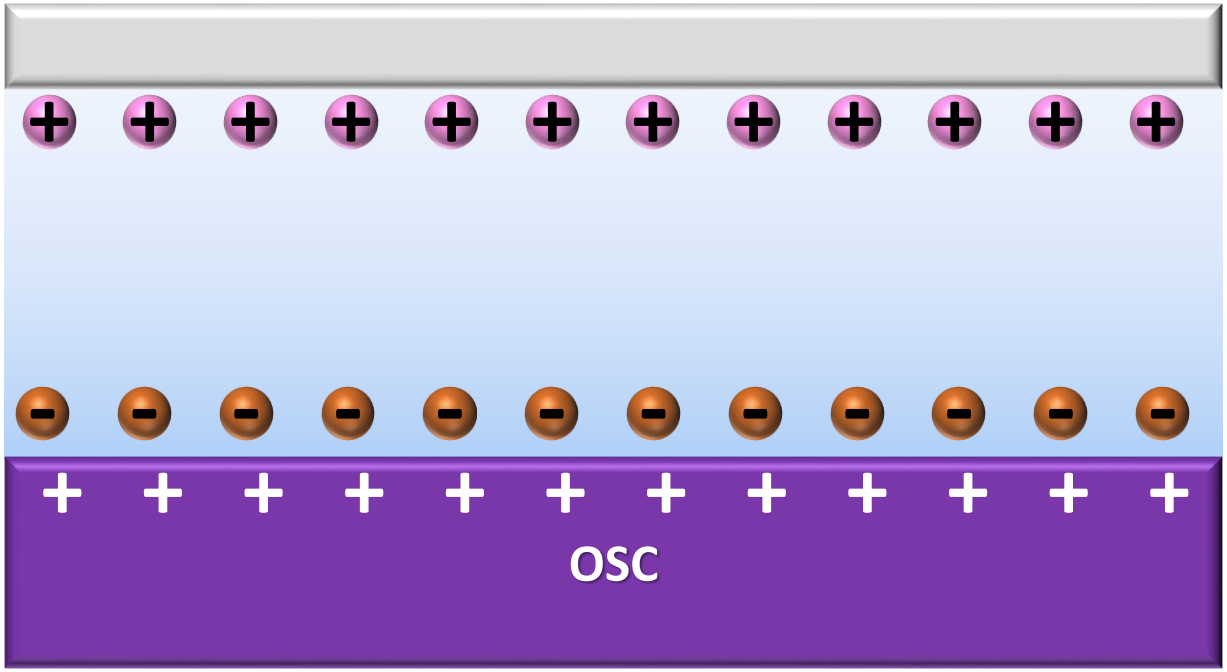
$$C_{dl} \cong \frac{\varepsilon}{\lambda_D} A$$

C_{dl} : 10 – 100 µF · cm^{-2}
C_{ins} : 10 nF · cm^{-2}

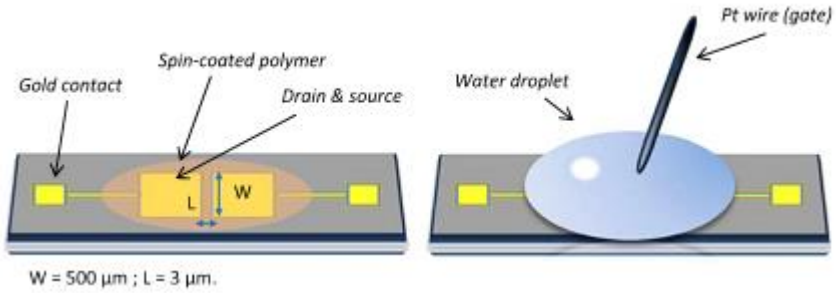


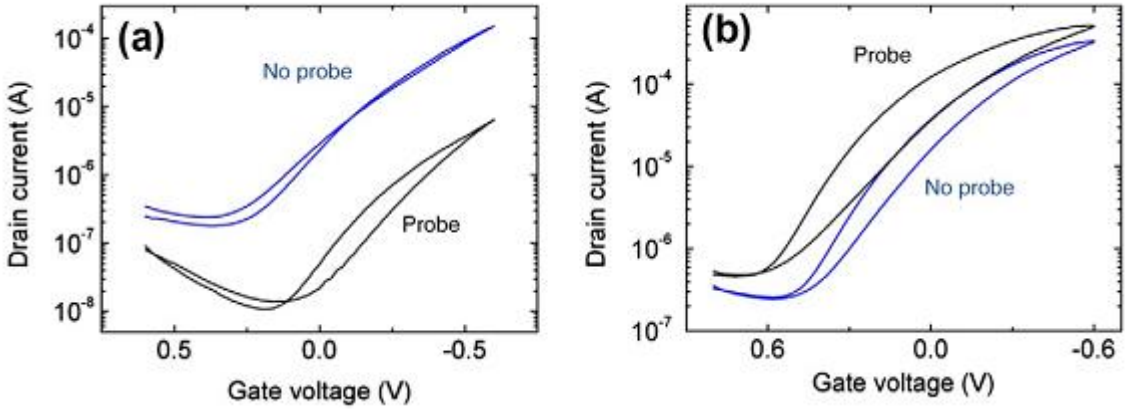
EGOFET

EGOFET: working principle



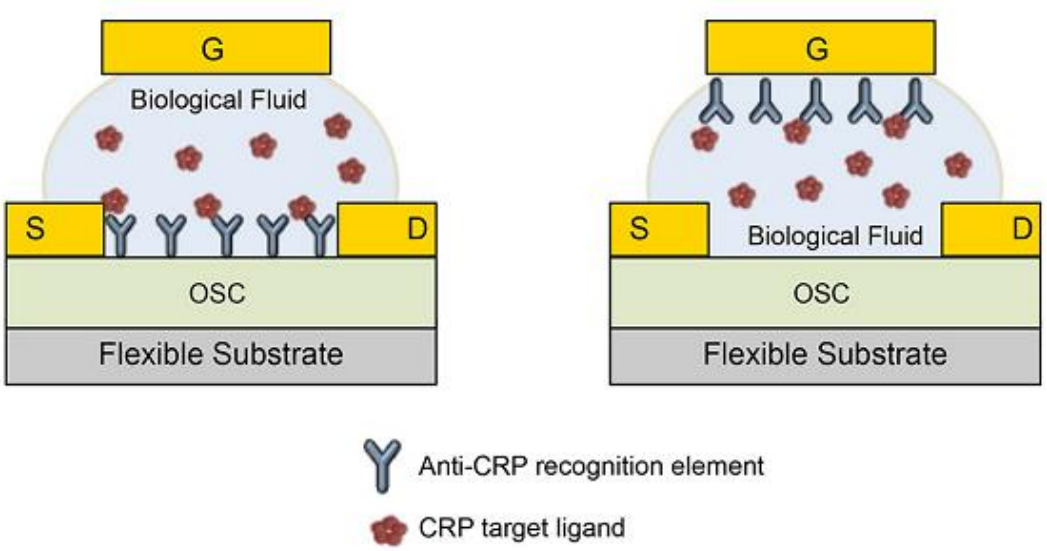
EGOFET: working principle

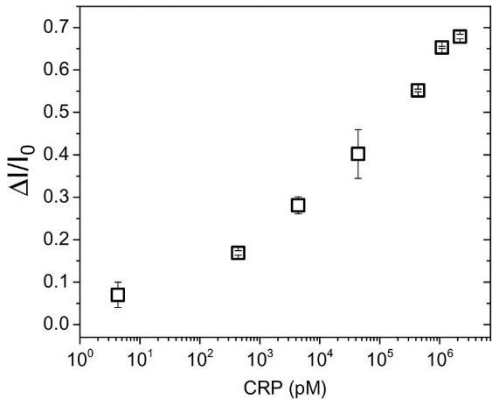




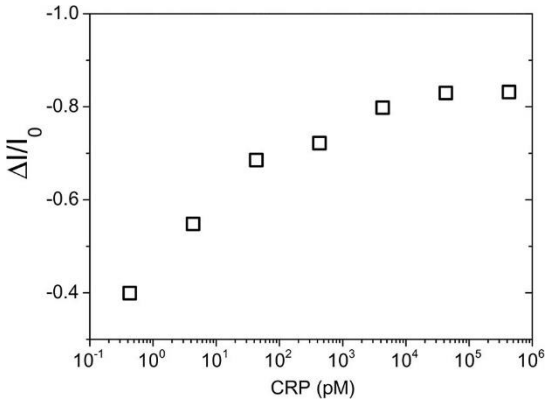
EGOFET: functionalization

Point-of-care (POC) biosensors are integrated diagnostic devices that allow the detection of clinically relevant biomarkers in biological fluids (blood, urine, saliva, sweat, and tears) outside conventional laboratories.





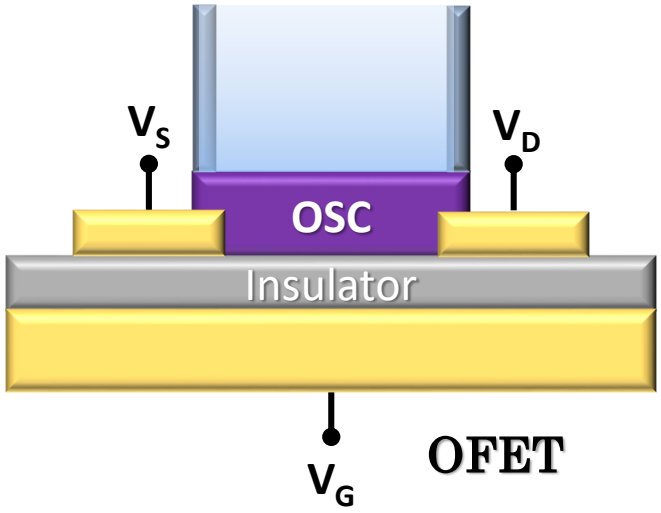
OSC



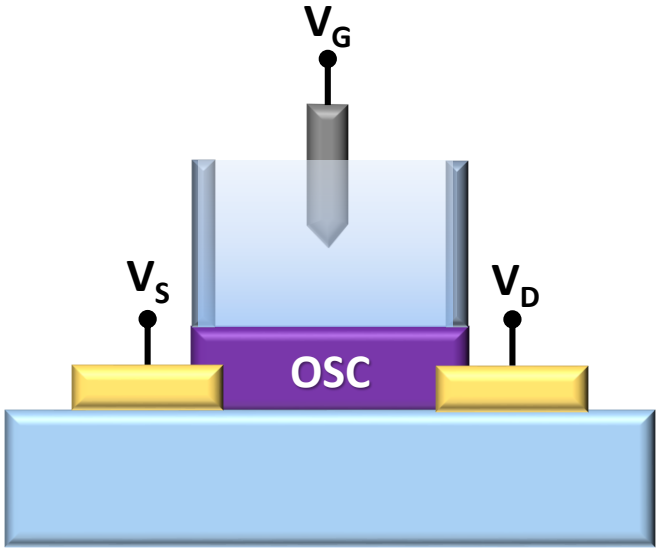
GATE

Ultrasensitive printable biosensors for point-of-care applications
Maria Magliulo, Mohammad Yusuf Mulla, Kyriaki Manoli, Donato De Tullio, Preethi Seshadri, Gaetano Scamarcio, Gerardo Palazzo and Luisa Torsi (2012)

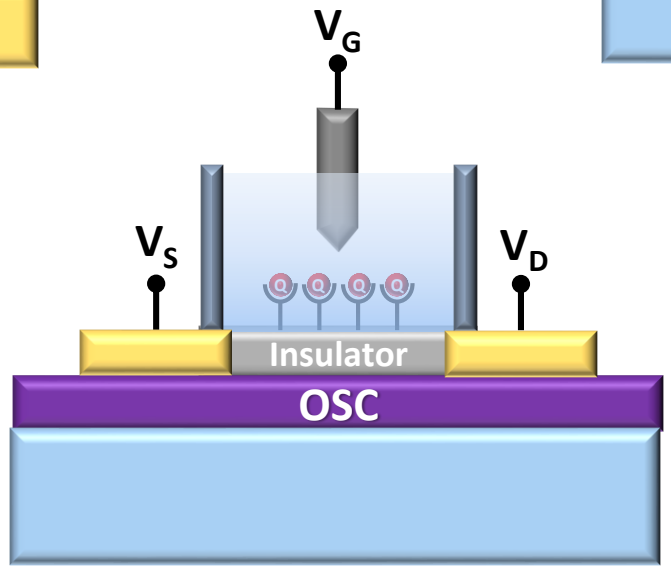
Structures



OFET

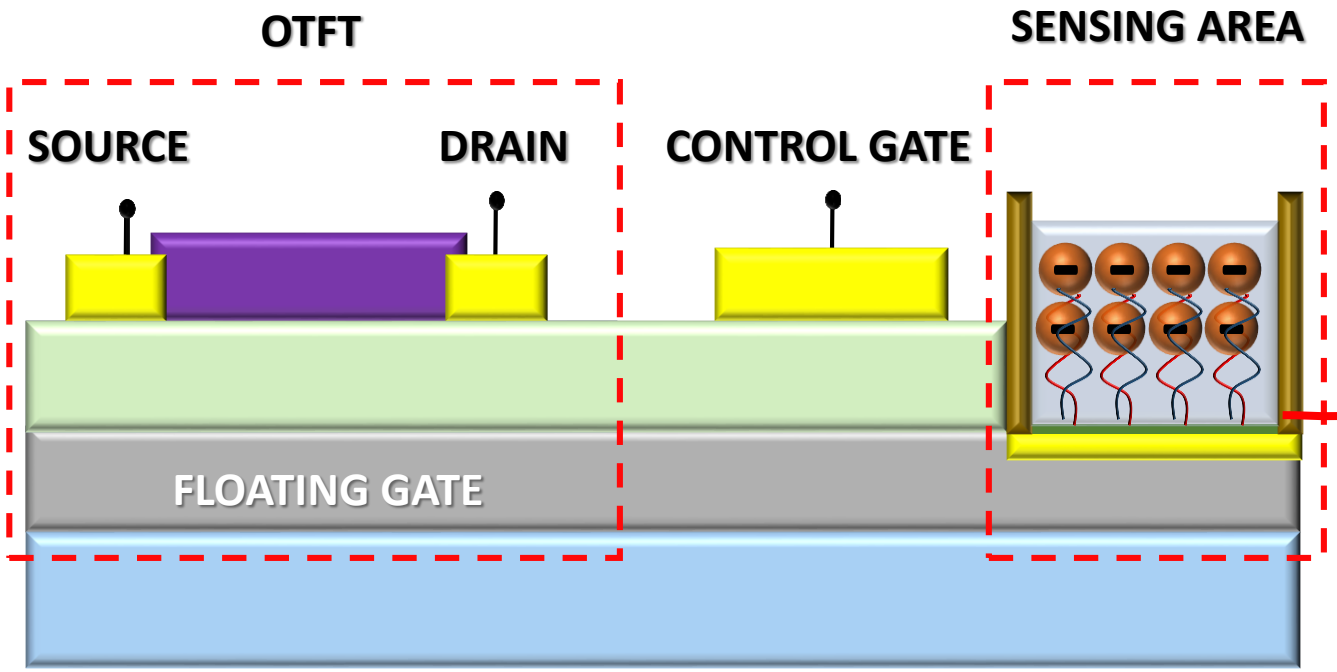


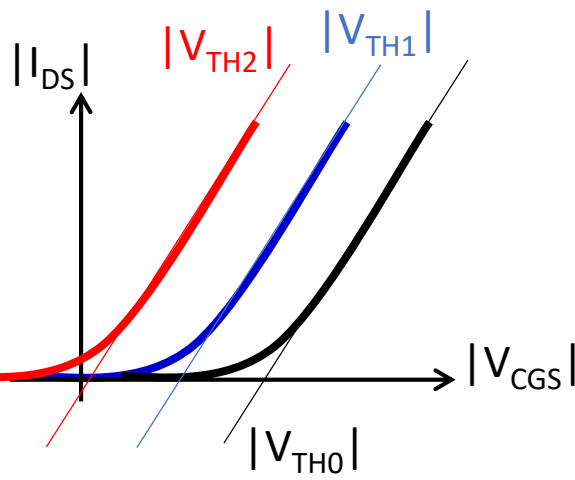
EGOFET



ISOFET

OCMFET: DNA hybridization

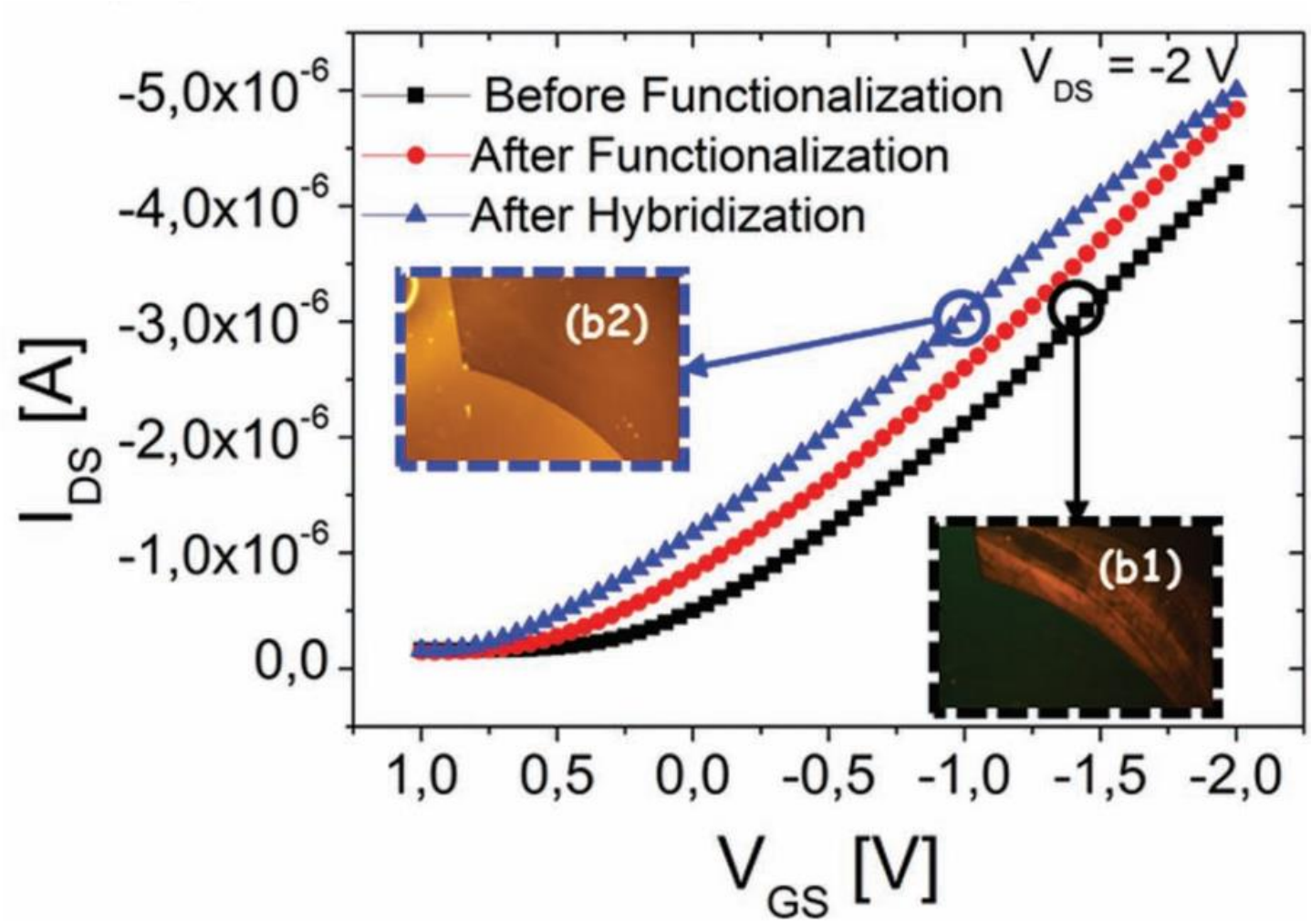




$$\Delta V_{TH} = \frac{\Delta Q_{SENS}}{C_{CG} + C_{DF} + C_{SF}}$$

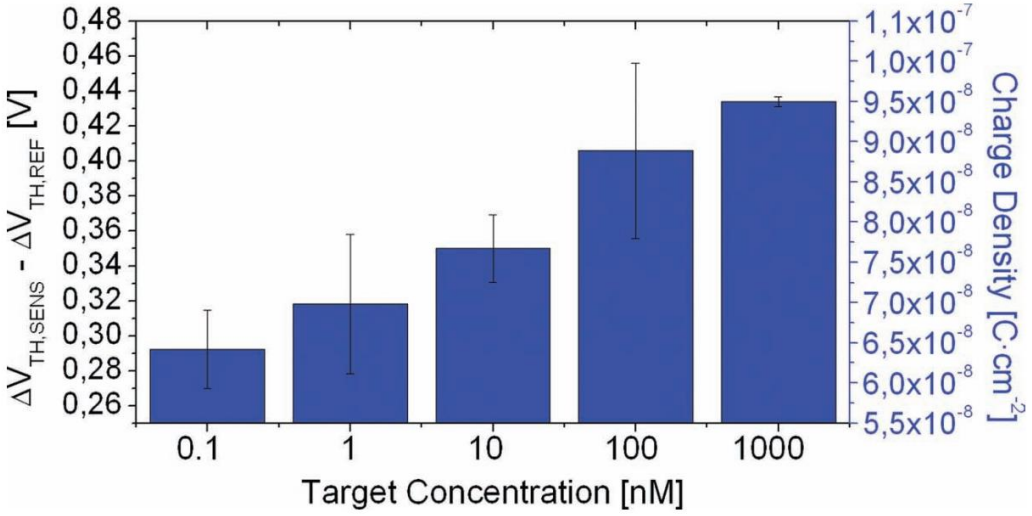
$$V_{FG} \approx \frac{C_{CG}}{C_{CG} + C_{DF} + C_{SF}} V_{CGS} + \frac{Q_{SENS}}{C_{CG} + C_{DF} + C_{SF}} + \frac{Q_0}{C_{CG} + C_{DF} + C_{SF}}$$

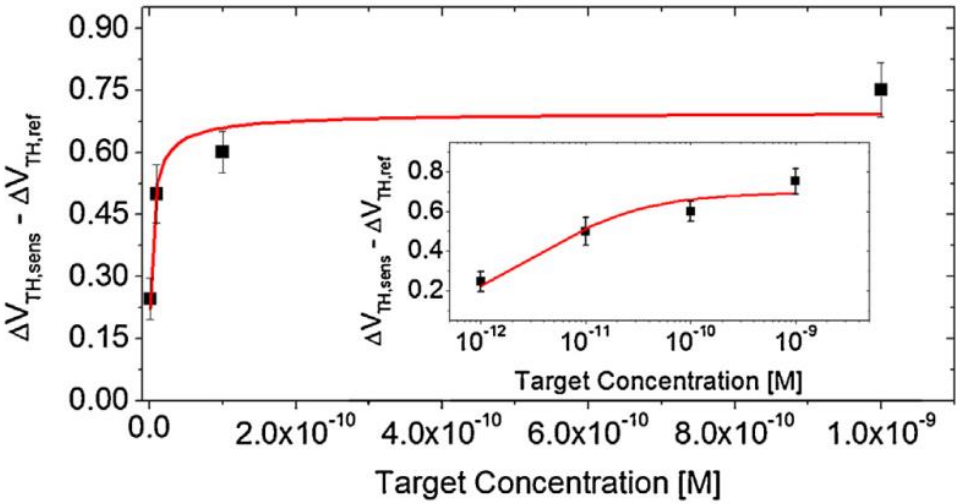
OCMFET: DNA hybridization

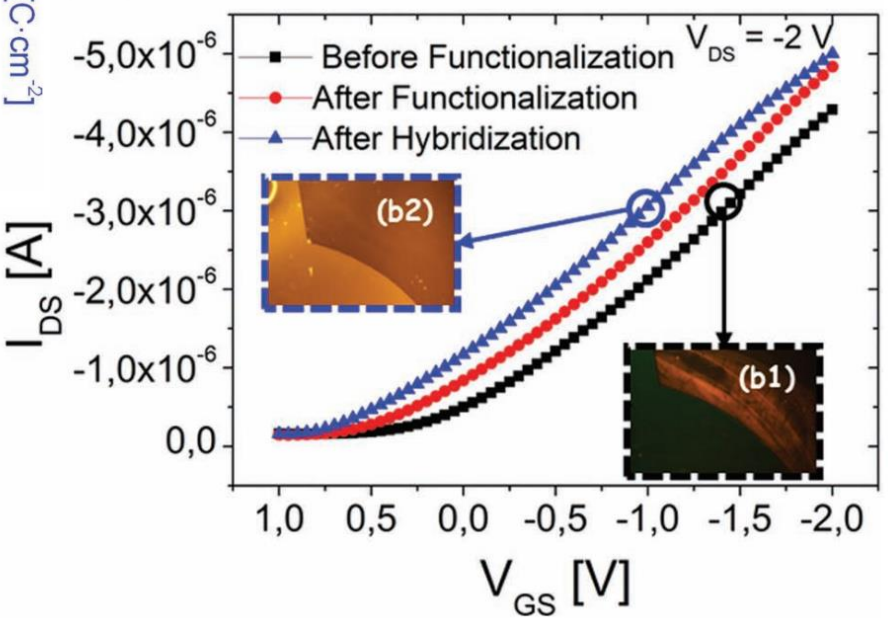


S. Lai, M. Demelas, G. Casula, P. Cosseddu, M. Barbaro, and A. Bonfiglio, **Adv. Mater.** 25, 103 (2013)

OCMFET: DNA hybridization

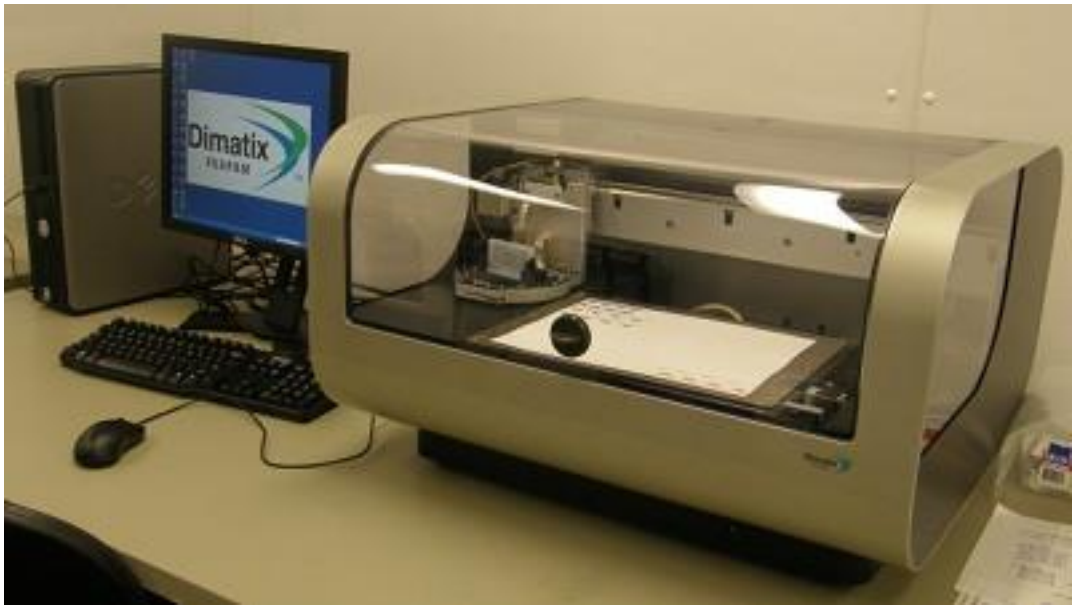


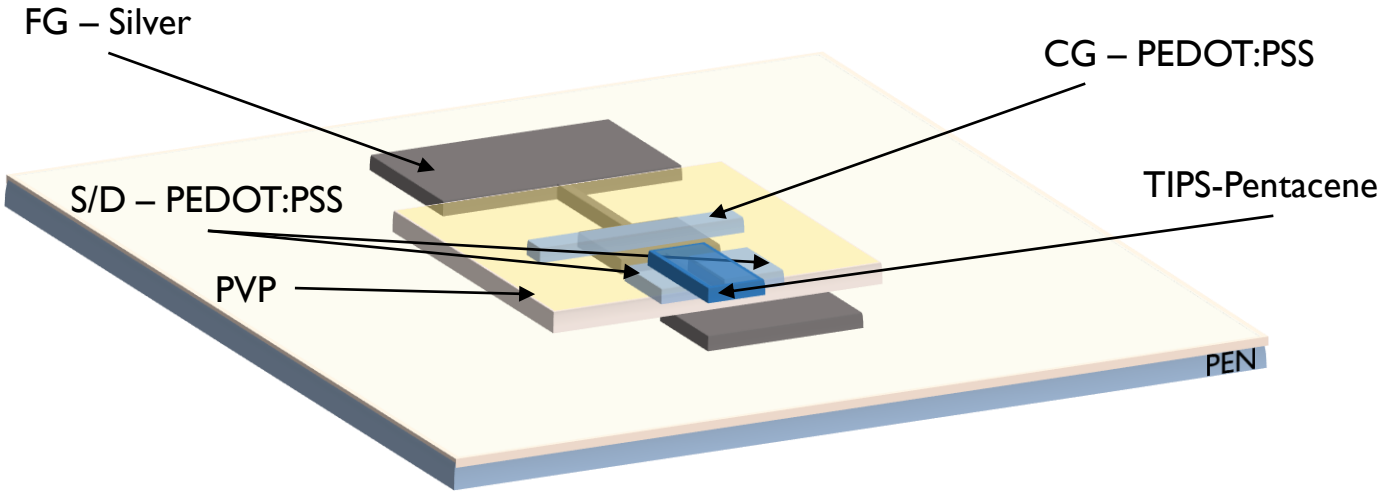




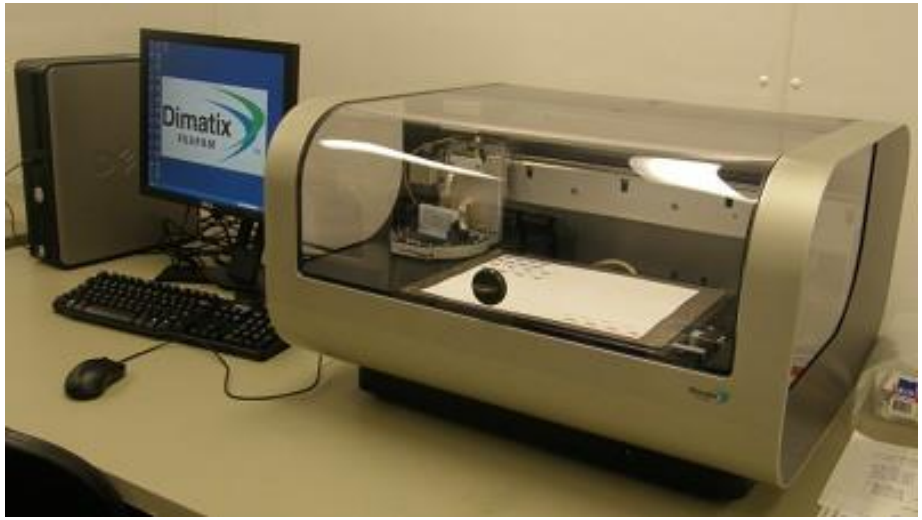
S. Lai, M. Demelas, G. Casula, P. Cosseddu, M. Barbaro, and A. Bonfiglio, **Adv. Mater.** 25, 103 (2013)

Inkjet printing

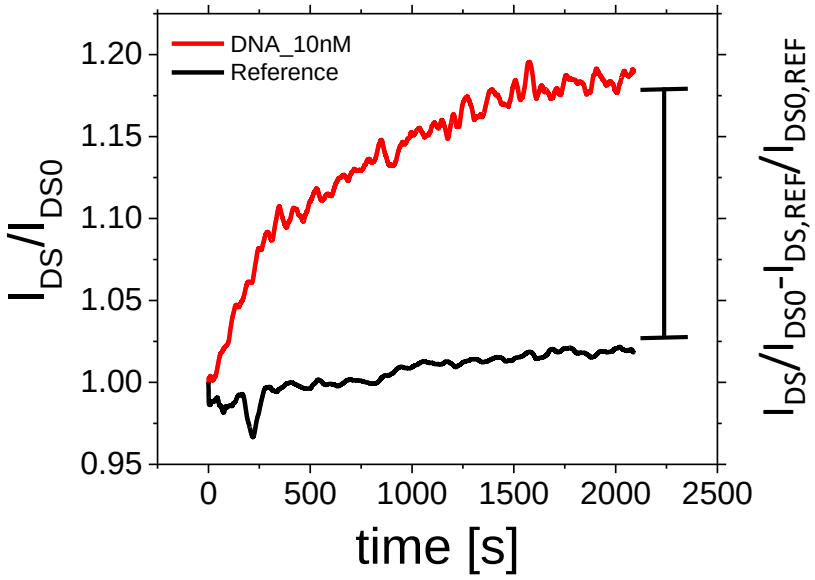




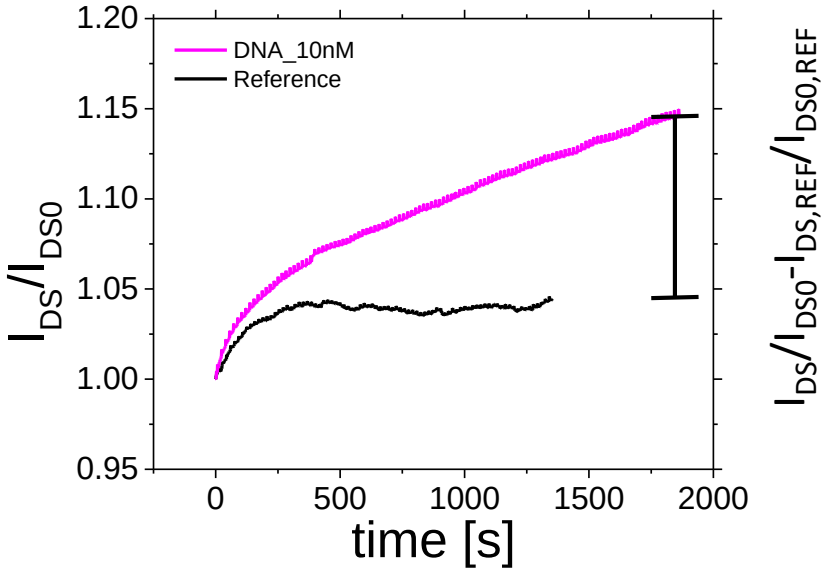
Inkjet printing



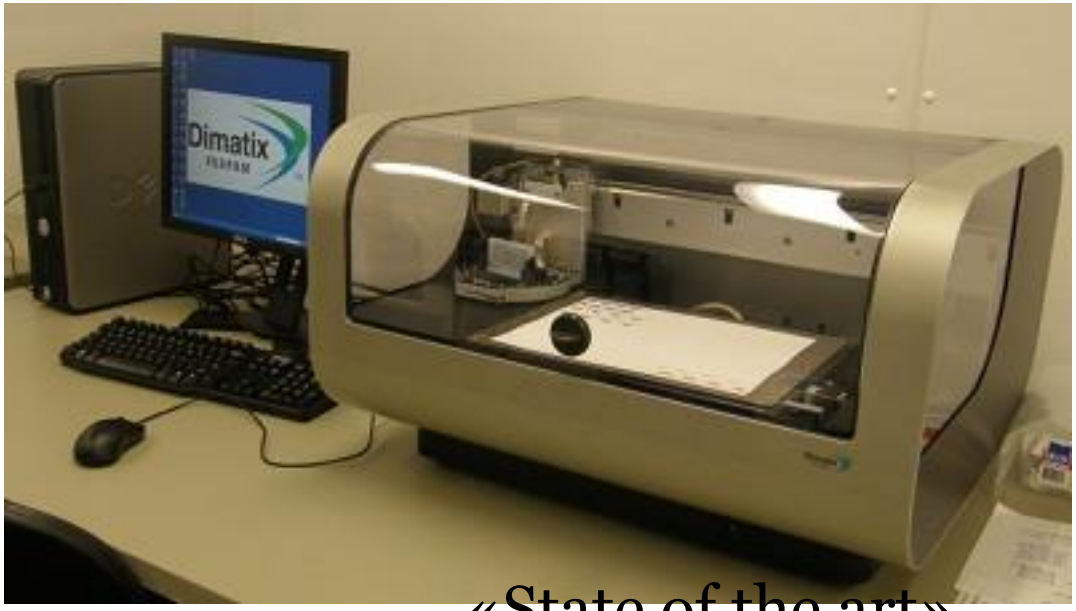
Printed



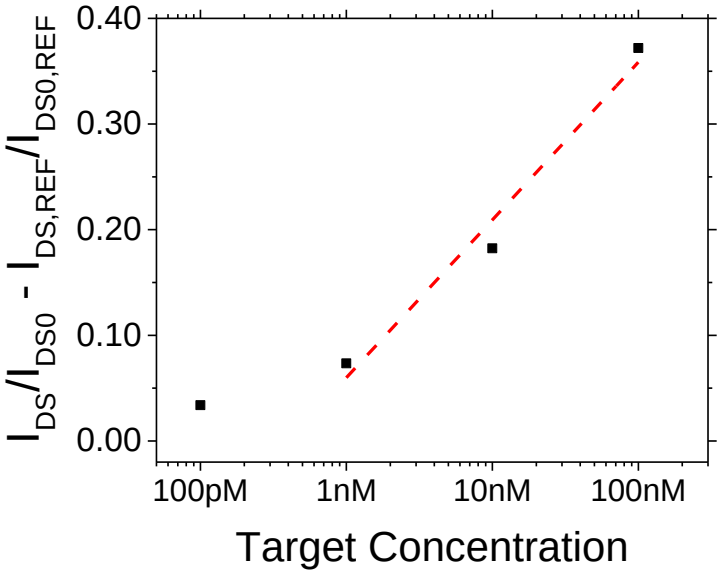
«State of the art»



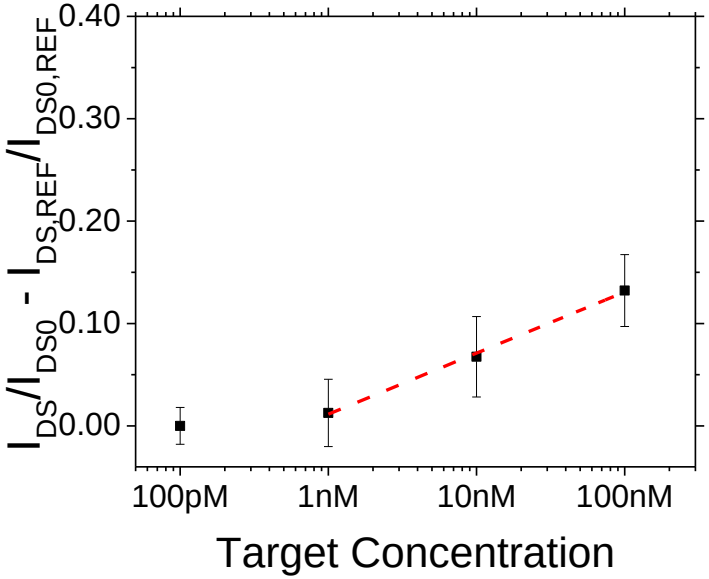
Inkjet printing



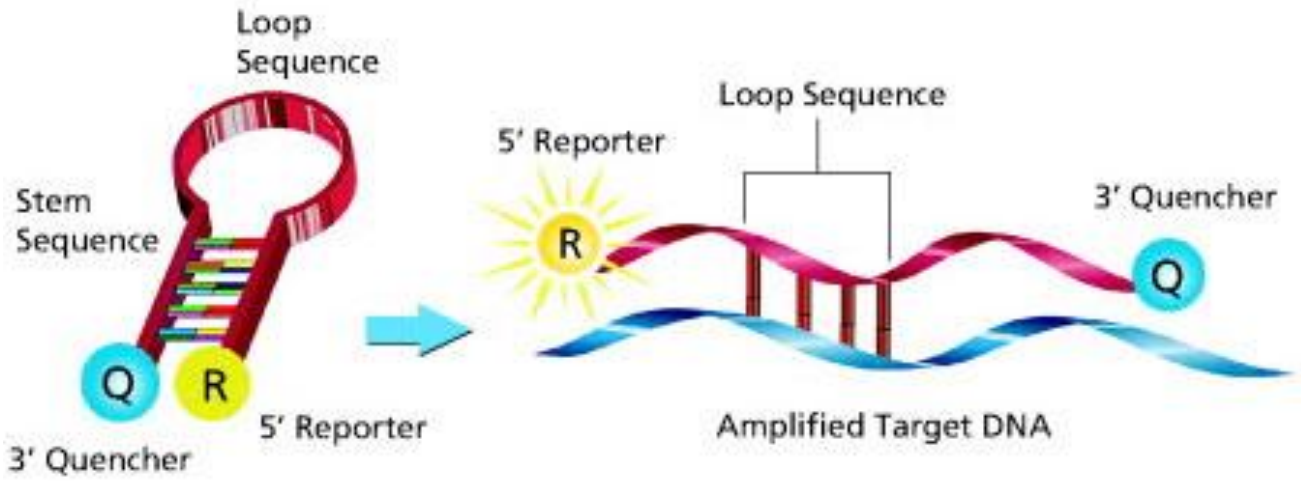
Printed



«State of the art»



OCMFET: Molecular beacons



OCMFET: Molecular beacons